

Site surveys

Once you determine the probable location of the pond, conduct a site survey to plan and design the dam, spillways, and other features. Those unfamiliar with the use of surveying instruments should employ a licensed surveyor or other qualified professional.

Pond surveys generally consist of a profile of the centerline of the dam, a profile of the centerline of the earth spillway, and enough measurements to estimate pond capacity. A simple method of estimating pond capacity is described on page 12. For larger and more complex ponds, particularly those used for water supply or irrigation, you may need a complete topographic survey of the entire pond site.

Run a line of profile level surveys along the centerline of the proposed dam and up both sides of the valley well above the expected elevation of the top of the dam and well beyond the probable location of the auxiliary spillway. The profile should show the surface elevation at all significant changes in slope and at intervals of no more than 100 feet. This line of levels establishes the height of the dam and the location and elevation of the earth spillway and the principal spillway. It is also used to compute the volume of earthfill needed to build the dam.

Run a similar line of profile levels along the centerline of the auxiliary spillway. Start from a point on the upstream end that is well below the selected normal water surface elevation and continue to a point on the downstream end where water can be safely discharged without damage to the dam. This line serves as a basis for determining the slope and dimensions of the spillway.

All surveys made at a pond site should be tied to a reference called a bench mark. This may be a large spike driven into a tree, an iron rod driven flush with the ground, a point on the concrete headwall of a culvert, or any object that will remain undisturbed during and after construction of the dam.

Embankment ponds

Detailed soils investigation

Soils in the ponded area—Suitability of a pond site depends on the ability of the soils in the reservoir area to hold water. The soil should contain a layer of material that is impervious and thick enough to prevent excessive seepage. Clays and silty clays are excellent for this purpose; sandy and gravelly clays are usually satisfactory. Generally, soils with at least 20 percent passing the No. 200 sieve, a Plasticity Index of more than 10 percent, and an undisturbed thickness of at least 3 feet do not have excessive seepage when the water depth is less than 10 feet. Coarse-textured sands and sand-gravel mixtures are highly pervious and therefore usually unsuitable. The absence of a layer of impervious material over part of the ponded area does not necessarily mean that you must abandon the proposed site. You can treat these parts of the area by one of several methods described later in this handbook. Any of these methods can be expensive.

Some limestone areas are especially hazardous as pond sites. Crevices, sinks, or channels that are not visible from the surface may be in the limestone below the soil mantle. They may empty the pond in a short time. In addition, many soils in these areas are granular. Because the granules do not break down readily in water, the soils remain highly permeable. All the factors that may make a limestone site undesirable are not easily recognized without extensive investigations and laboratory tests. The best clue to the suitability of a site in one of these areas is the degree of success others have had with farm ponds in the immediate vicinity.

Unless you know that the soils are sufficiently impervious and that leakage will not be a problem, you should make soil borings at intervals over the area to be covered with water. Three or four borings per acre may be enough if the soils are uniform. More may be required if there are significant differences.

Foundation conditions—The foundation under a dam must ensure stable support for the structure and provide the necessary resistance to the passage of water.

Soil borings help to investigate thoroughly the foundation conditions under the proposed dam site. The depth of the holes should be at least 1-1/2 times the height of the proposed dam. Ensure there are not any steep dropoffs in the rock surface of the foundation under the dam. Steep dropoffs in the rock surface can result in cracking of the embankment. Study the natural banks (abutments) at the ends of the dam as well as the supporting materials under the dam. If the dam is to be placed on rock, the rock must be examined for thickness and for fissures and seams through which water might pass.

Coarse-textured materials, such as gravel, sand, and gravel-sand mixtures, provide good support for a dam, but are highly pervious and do not hold water. Such materials can be used only if they are sealed to prevent seepage under the dam. You can install a cutoff core trench of impervious material under the dam or blanket the upstream face of the dam and the pond area with a leak-resistant material.

Fine-textured materials, such as silts and clays, are relatively impervious, but have a low degree of stability. They are not good foundation materials, but generally are satisfactory for the size of dams discussed in this handbook. Flattening the side slopes of some dams may be necessary to reduce the unit load on the foundation. Remove peat, muck, and any soil that has a high organic-matter content from the foundation.

Good foundation materials, those that provide both stability and imperviousness, are a mixture of coarse- and fine-textured soils. Some examples are gravel-sand-clay mixtures, gravel-sand-silt mixtures, sand-clay mixtures, and sand-silt mixtures.

Less desirable but still acceptable foundation materials for ordinary pond dams are gravelly clays, sandy clays, silty clays, silty and clayey fine sands, and clayey silts that have slight plasticity.

Fill material—The availability of suitable material for building a dam is a determining factor in selecting a pond site. Enough suitable material should be located close to the site so that placement costs are not excessive. If fill material can be taken from the reservoir area, the surrounding landscape will be left undisturbed and borrow areas will not be visible after the pond has been filled (fig. 18).

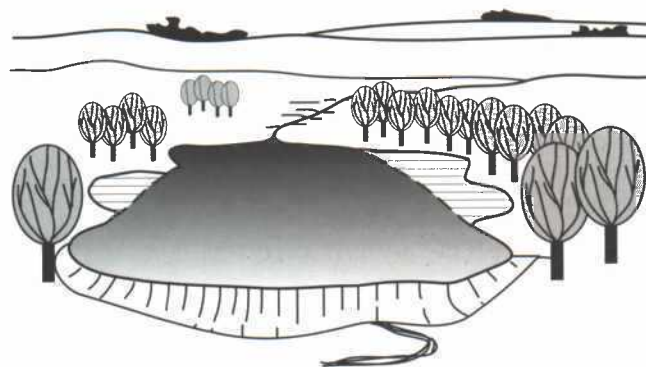
Materials selected must have enough strength for the dam to remain stable and be tight enough, when properly compacted, to prevent excessive or harmful percolation of water through the dam. Soils described as acceptable for foundation material generally are acceptable for fill material. The exceptions are organic silts and clays.

The best material for an earthfill contains particles ranging from small gravel or coarse sand to fine sand and clay in the desired proportions. This material should contain about 20 percent, by weight, clay particles. Though satisfactory earthfills can be built from soils that vary from the ideal, the greater the variance, the more precautions needed.

Soils containing a high percentage of gravel or coarse sand are pervious and can allow rapid seepage through the dam. When using these soils, place a core of clay material in the center of the fill and flatten the side slopes to keep the line of seepage from emerging on the downstream slope.

Fill material that has a high clay content swells when wet and shrinks when dry. The shrinkage may open dangerous cracks. If these soils are dispersive, they represent a serious hazard to the safety of the embankment and should be avoided. Dispersive soils can be identified by how easily they go into suspension in water, by the presence of a gelatinous cloud around a clod of soil in distilled water, and by the indefinite

Figure 18 Borrow material taken from within the reservoir area creates an irregular pond configuration



length of time they stay in suspension in still water. High sodium soils identified in the soil survey for the planned area of the embankment also indicate dispersive soils. If any of these indicators are found at the proposed site, an engineer should be hired to provide the necessary guidance for sampling, testing, and using these soils for fill. For soils consisting mostly of silt, such as the loess areas of western Iowa and along the Mississippi River in Arkansas, Mississippi, and Tennessee, the right degree of moisture must be maintained during construction for thorough compaction.

To estimate the proportion of sand, silt, and clay in a sample of fill material, first obtain a large bottle with straight sides. Take a representative sample of the fill material and remove any gravel by passing the material through a 1/4-inch sieve or screen. Fill the bottle to about one-third with the sample material and finish filling with water. Shake the bottle vigorously for several minutes and then allow the soil material to settle for about 24 hours. The coarse material (sand) settles to the bottom first, and finer material (clay) settles last. Estimate the proportion of sand, silt, and clay by measuring the thickness of the different layers with a ruler.

Landscape planning—The pond should be located and designed to blend with the existing landform, vegetation, water, and structures with minimum disturbance. Landforms can often form the impoundment with minimum excavation. Openings in the vegetation can be used to avoid costly clearing and grubbing. Existing structures, such as stone walls and trails, can be retained to control pedestrian and vehicular traffic and minimize disruption of existing use. In the area where land and water meet, vegetation and landform can provide interesting reflections on the water's surface, guide attention to or from the water, frame the water to emphasize it, and direct passage around the pond.

A pond's apparent size is not always the same as its actual size. For example, the more sky reflected on the water surface, the larger a pond appears. A pond surrounded by trees will appear smaller than a pond the same size without trees or with some shoreline trees (fig. 19). The shape of a pond should complement its surroundings. Irregular shapes with smooth, flowing shorelines generally are more compatible with the patterns and functions found in most landscapes.

Peninsulas, inlets, or islands can be constructed to create diversity in the water's edge.

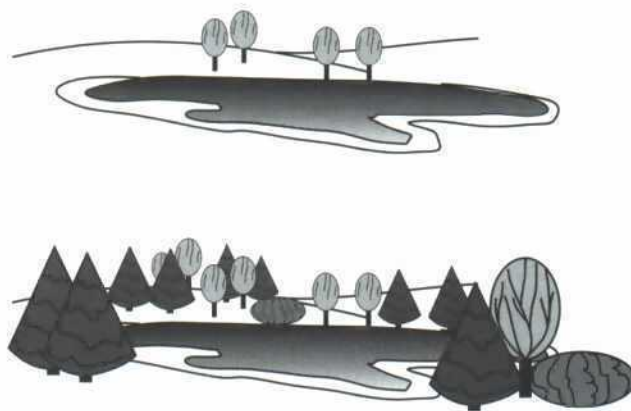
Spillway requirements

A pipe spillway often is used as well as an earth auxiliary spillway to control runoff from the watershed. The principal spillway is designed to reduce the frequency of operation of the auxiliary spillway. Commonly the principal spillway may be a hooded or canopy inlet with a straight pipe or may be a drop inlet (vertical section) that has a pipe barrel through the dam. The pipe shall be capable of withstanding external loading with yielding, buckling, or cracking. The pipe joints and all appurtenances need to be watertight. Pipe materials may be smooth metal, corrugated metal, or plastic. Design limitations exist with all materials.

A small principal spillway pipe, formerly called a trickle tube, only handles a small amount of flow. Its purpose is to aid in keeping the auxiliary spillway dry during the passage of small storm events.

Hooded or canopy inlets are common. A disadvantage of this type inlet is the larger amount of stage (head over the inlet crest) needed to make the pipe flow at full capacity. Conversely, a drop inlet spillway requires less stage because the size of the inlet may be enlarged to make the barrel flow full.

Figure 19 The apparent size of the pond is influenced by surrounding vegetation



The principal spillway normally is sized to control the runoff from a storm ranging from a 1-year to a 10-year frequency event. This depends on the size of the drainage area. For pond sites where the drainage area is small (less than 20 acres) and the condition of the vegetated spillway is good, no principal spillway is required except where the pond is spring fed or there are other sources of steady baseflow. In this case, a trickle tube shall be installed.

Earth spillways have limitations. Use them only where the soils and topography allow the peak flow to discharge safely at a point well downstream and at a velocity that does not cause appreciable erosion either within the spillway or beyond its outlet.

Soil borings generally are required for auxiliary spillways if a natural site with good plant cover is available. If spillway excavation is required, the investigations should be thorough enough to determine whether the soils can withstand reasonable velocities without serious erosion. Avoid loose sands and other highly erodible soils.

No matter how well a dam has been built, it will probably be destroyed during the first severe storm if the capacity of the spillway is inadequate. The function of an auxiliary spillway is to pass excess storm runoff around the dam so that water in the pond does not rise high enough to damage the dam by overtopping. The spillways must also convey the water safely to the

outlet channel below without damaging the downstream slope of the dam. The proper functioning of a pond depends on a correctly designed and installed spillway system.

Auxiliary spillways should have the minimum capacity to discharge the peak flow expected from a storm of the frequency and duration shown in table 7 less any reduction creditable to conduit discharge and detention storage. After the spillway capacity requirements are calculated, the permissible velocity must be determined. Table 8 shows the recommended allowable velocity for various cover, degree of erosion resistance, and slope of the channel. Table 9 gives the retardance factors for the expected height of the vegetation.

Both natural and excavated auxiliary spillways are used. A natural spillway does not require excavation to provide enough capacity to conduct the pond outflow to a safe point of release (fig. 20). The requirements discussed later for excavated spillways do not apply to natural spillways, but the capacity must be adequate.

With the required discharge capacity (Q), the end slope of the embankment (Z_1), and the slope of the natural ground (Z_2) known, the maximum depth of water above the level portion (H_p) can be obtained from table 10. The depth is added to the elevation of the spillway crest to determine the maximum elevation to which water will rise in the reservoir.

Table 7 Minimum spillway design storm

Drainage area (acre)	Effective height of dam ^{1/} (ft)	Storage (acre-ft)	Minimum design storm	
			Frequency (yr)	Minimum duration (hr)
20 or less	20 or less	Less than 50	10	24
20 or less	More than 20	Less than 50	25	24
More than 20	20 or less	Less than 50	25	24
All others			50	24

^{1/} The effective height of the dam is the difference in elevation between the auxiliary spillway crest and the lowest point in the cross section taken along the centerline of the dam.

Table 8 Permissible velocity for vegetated spillways ^{1/}

Vegetation	Permissible velocity ^{2/}			
	Erosion-resistant soils ^{3/}		Easily eroded soils ^{4/}	
	Slope of exit channel (%)			
	0-5 (ft/s)	5-10 (ft/s)	0-5 (ft/s)	5-10 (ft/s)
Bermudagrass	8	7	6	5
Bahiagrass	8	7	6	5
Buffalograss	7	6	5	4
Kentucky bluegrass	7	6	5	4
Smooth brome	7	6	5	4
Tall fescue	7	6	5	4
Reed canarygrass	7	6	5	4
Sod-forming grass-legume mixtures	5	4	4	3
Lespedeza sericea	3.5	3.5	2.5	2.5
Weeping lovegrass	3.5	3.5	2.5	2.5
Yellow bluestem	3.5	3.5	2.5	2.5
Native grass mixtures	3.5	3.5	2.5	2.5

^{1/} SCS TP-61

^{2/} Increase values 10 percent when the anticipated average use of the spillway is not more frequent than once in 5 years, or 25 percent when the anticipated average use is not more frequent than once in 10 years.

^{3/} Those with a higher clay content and higher plasticity. Typical soil textures are silty clay, sandy clay, and clay.

^{4/} Those with a high content of fine sand or silt and lower plasticity, or nonplastic. Typical soil textures are fine sand, silt, sandy loam, and silty loam.

Table 9 Guide to selection of vegetal retardance

Stand	Average height of vegetation (in)	Degree of retardance
Good	Higher than 30	A
	11 to 24	B
	6 to 10	C
	2 to 6	D
	Less than 2	E
Fair	Higher than 30	B
	11 to 24	C
	6 to 10	D
	2 to 6	D
	Less than 2	E

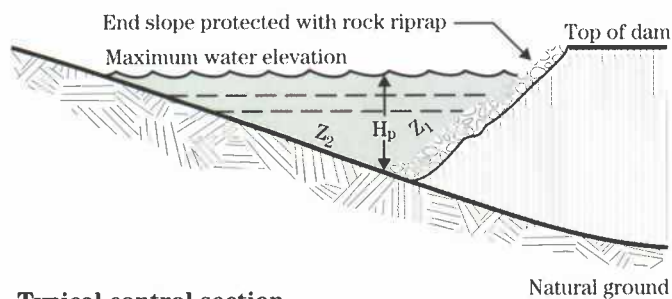
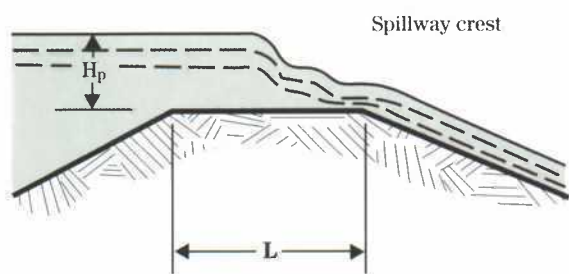
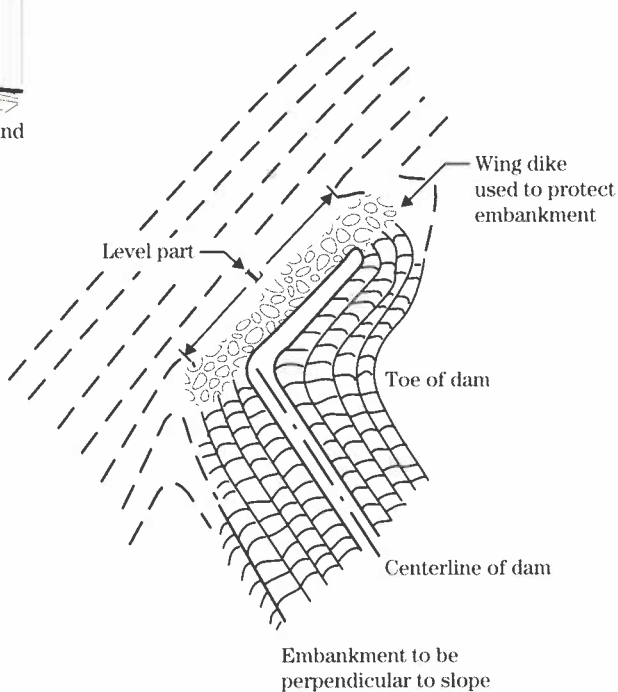
Figure 20 Plan, profile, and cross section of a natural spillway with vegetation**Typical control section****Profile****Plan view**

Table 10 H_p discharge and velocities for natural vegetated spillways with 3:1 end slope (Z_1)

Natural ground slope Z_2 (%)	H_p (ft)	-----A-----		-----B-----		Retardance -----C-----		-----D-----		-----E-----		-----Slope-----	
		Q (ft ³ /s)	V (ft/s)	Q (ft ³ /s)	V (ft/s)	Q (ft ³ /s)	V (ft/s)	Q (ft ³ /s)	V (ft/s)	Q (ft ³ /s)	V (ft/s)	Min. (%)	Max. (%)
0.5	1.0	19	0.3	28	0.5	47	1.3	68	1.8	130	2.8	0.5	3
	1.1	21	.3	35	.5	76	1.5	108	2.1	154	3.0		
	1.2	29	.4	39	.6	97	1.6	122	2.3	204	3.2		
	1.3	36	.4	53	.6	125	2.0	189	2.5	250	3.4		
	1.5	61	.4	87	1.1	210	2.2	291	2.9	393	3.8		
	1.8	81	.5	187	1.8	384	2.9	454	3.5	651	4.5		
	2.0	110	.5	286	2.1	524	3.3	749	3.8	860	4.8		
1	1.0	10	0.4	16	0.5	31	2.0	45	2.6	64	3.4	1	3
	1.1	13	.4	18	.6	50	2.3	63	2.8	90	3.7		
	1.2	15	.5	21	.8	62	2.5	78	3.1	99	4.0		
	1.3	22	.6	39	1.0	86	2.7	144	3.4	139	4.3		
	1.5	40	.7	75	1.8	133	3.1	186	4.0	218	5.1		
	1.8	56	.8	126	2.3	280	3.8	296	4.5				
	2.0	98	1.1	184	2.8	328	4.3	389	5.0				
2	1.0	6	0.5	9	0.8	18	2.5	27	3.3	36	4.2	1	3
	1.1	7	.7	14	1.0	29	2.8	39	3.6	50	4.5		
	1.2	9	.8	19	1.1	40	3.1	51	3.9	64	4.9		
	1.3	13	.9	26	1.6	50	3.4	70	4.3	85	5.3		
	1.5	21	1.0	39	2.0	70	3.9	109	5.1	127	6.3		
	1.8	26	1.1	74	2.5	126	4.8	194	5.9				
	2.0	52	1.3	111	3.2	190	5.4	229	6.4				
3	1.0	4	0.7	7	0.8	15	2.8	21	3.7	28	4.8	1	3
	1.1	5	.8	10	.9	24	3.2	31	4.0	38	5.2		
	1.2	7	.9	14	1.1	33	3.6	41	4.4	49	5.6		
	1.3	10	1.0	20	1.5	42	3.8	57	4.8	67	6.1		
	1.5	16	1.2	34	2.8	62	4.4	89	5.7	104	7.2		
	1.8	23	1.3	57	3.0	112	5.5	143	6.7				
	2.0	39	1.5	81	3.7	163	6.2	194	7.2				
4	1.2	6	1.0	11	1.4	25	3.9	31	4.8	38	6.1	1	4
	1.5	15	1.3	29	3.1	49	4.8	69	5.5	81	7.9		
	1.8	20	1.4	47	4.1	98	6.1	116	7.3				
	2.0	30	1.6	65	4.7	139	6.7	161	7.8				
	2.5	72	3.3	167	6.6	238	8.5						
5	1.5	13	1.4	23	3.3	38	5.2	55	6.7	63	8.4	1	5
	1.8	17	1.5	37	4.4	76	6.5	95	7.9				
	2.0	23	1.7	48	5.1	112	7.1	130	8.1				
	2.5	64	3.7	149	7.1	191	9.2						

The following example shows how to use table 10:

Given:

Vegetation: good stand of bermudagrass
Height: 6 to 10 inches
Slope of natural ground: 1.0 percent

Solution:

From table 9, determine a retardance of C.

From table 10, under natural ground slope
1 percent and retardance C column,
find $Q = 88$
ft³/s at $H_p = 1.3$ ft, and
 $V = 2.7$ ft/s.

If the freeboard is 1.0 foot, the top of the dam should be constructed 2.3 feet higher than the spillway crest. The velocity is well below the maximum permissible velocity of 6 feet per second given in table 8. H_p can be determined by interpolation when necessary. For a Q greater than that listed in table 10, the spillway should be excavated according to the information in the next section, Excavated auxiliary spillways.

Excavated auxiliary spillways—Excavated spillways consist of the three elements shown in figure 21. The flow enters the spillway through the inlet channel. The maximum depth of flow (H_p) located upstream from the level part is controlled by the inlet channel, level part, and exit channel.

Excavation of the inlet channel or the exit channel, or both, can be omitted where the natural slopes meet the minimum slope requirements. The direction of slope of the exit channel must be such that discharge does not flow against any part of the dam. Wing dikes, sometimes called kicker levees or training levees, can be used to direct the outflow to a safe point of release downstream.

The spillway should be excavated into the earth for its full depth. If this is not practical, the end of the dam and any earthfill constructed to confine the flow should be protected by vegetation or riprap. The entrance to the inlet channel should be widened so it is at least 50 percent greater than the bottom width of the level part. The inlet channel should be reasonably short and should be planned with smooth, easy curves for alignment. It should have a slope toward the reser-

voir of not less than 2.0 percent to ensure drainage and low water loss at the inlet.

With the required discharge capacity, the degree of retardance, permissible velocity, and the natural slope of the exit channel known, the bottom width of the level and exit sections and the depth of the flow (H_p) can be computed using the figures in table 11. This table shows discharge per foot of width. The natural slope of the exit channel should be altered as little as possible.

The selection of the degree of retardance for a given auxiliary spillway depends mainly on the height and density of the cover chosen (table 9). Generally, the retardance for uncut grass or vegetation is the one to use for capacity determination. Because protection and retardance are lower during establishment and after mowing, to use a lower degree of retardance when designing for stability may be advisable.

The following examples show the use of the information in table 11:

Example 1 where only one retardance is used for capacity and stability:

Given:

$Q = 87$ ft³/s (total design capacity)
 $S_o = 4$ percent (slope of exit channel determined from profile, or to be excavated)
 $L = 50$ ft

Earth spillway is to be excavated in an erosion-resistant soil and planted with a sod-forming grass-legume mixture. After establishment, a good stand averaging from 6 to 10 inches in height is expected.

Required:

Permissible velocity (V)
Width of spillway (b)
Depth of water in the reservoir above the crest (H_p).

Solution:

From table 8 for sod-forming grass-legume mixtures, read permissible velocity $V = 5$ ft/s.

From table 9 for average height of vegetation of 6 to 10 inches, determine retardance C.

For retardance C, enter table 11 from left at maximum velocity $V = 5$ ft/s. A 4 percent slope is in the slope range of 1–6 with Q of 3 ft³/s/ft.

H_p for L of 50 ft = 1.4 ft.

If the freeboard is 1 foot, the spillway should be constructed 29 feet wide and 2.4 feet deep.

For retardance C, enter table 11 from left at maximum velocity $V = 5$ ft/s. A 4 percent slope is in the slope range of 1–6 with Q of 3 ft³/s/ft.

H_p for L of 50 ft = 1.4 ft.

If the freeboard is 1 foot, the spillway should be constructed 29 feet wide and 2.4 feet deep.

Example 2 where one retardance is used for stability and another is used for capacity:

Given:

S_o = 4 percent (slope of exit channel determined from profile or to be excavated)

L = 50 ft

Earth spillway is to be excavated in a highly erodible soil and planted with bahiagrass. After establishment a good stand of 11 to 24 inches is expected.

Required:

Permissible velocity (V)

Width of spillway (b)

Depth of water in reservoir above the crest (H_p).

Solution:

From table 8 determine permissible velocity for bahiagrass in a highly erodible soil that has 8 percent slope $V = 5$ ft/s.

From table 9, select retardants to be used for stability during an establishment period that has a good stand of vegetation of 2 to 6 inches (retardance D).

Select retardance to be used for capacity for good stand of vegetation that has a length of 11 to 24 inches (retardance B).

From table 11, enter from left at maximum velocity $V = 5$ ft/s. A slope of 6 percent is in the range for $Q = 2$ ft³/s/ft.

Then

From table 11, enter $q = 2$ ft³/s/ft under retardance B and find H_p for L of 25 ft = 1.4 ft.

If the freeboard is 1 foot, the spillway should be constructed 50 feet wide and 2.4 feet deep.

Protection against erosion—Protect auxiliary spillways against erosion by establishing good plant cover if the soil and climate permit. As soon after construction as practicable, prepare the auxiliary spillway area for seeding or sodding by applying fertilizer or manure. Sow adapted perennial grasses and protect the seedlings to establish a good stand. Mulching is necessary on the slopes. Irrigation is often needed to ensure good germination and growth, particularly if seeding must be done during dry periods. If the added cost is justified, sprigging or sodding suitable grasses, such as bermudagrass, gives quick protection.

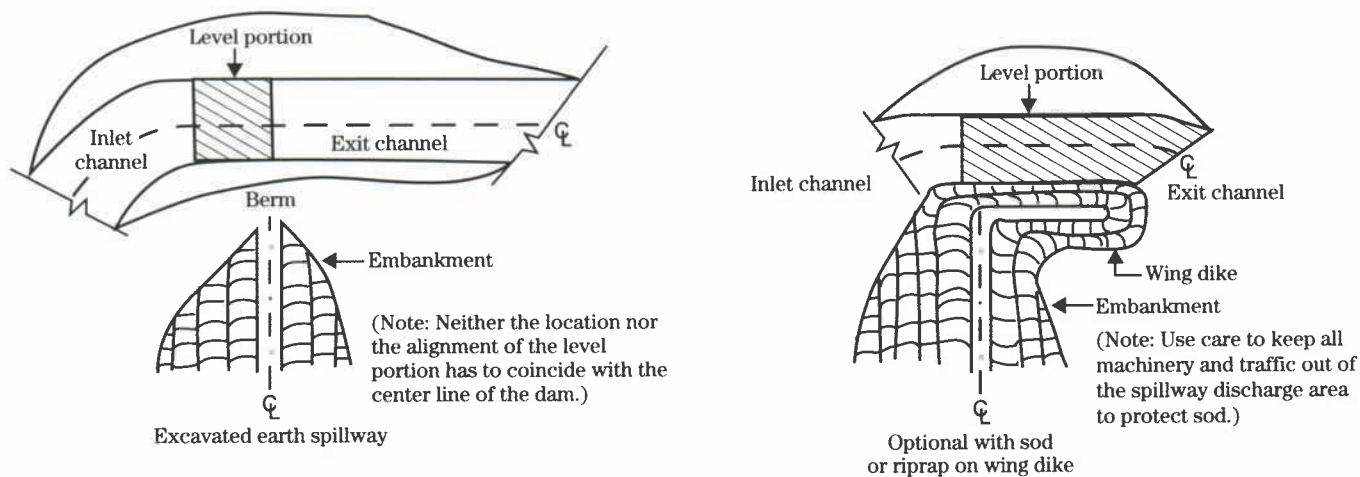
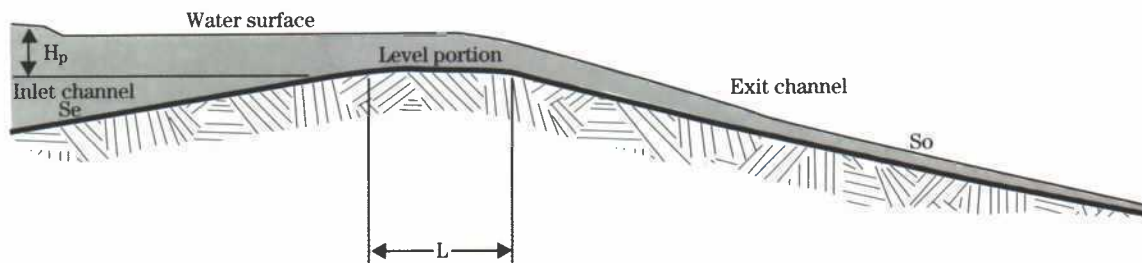
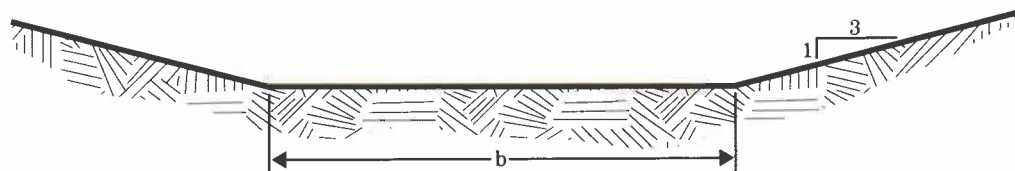
Figure 21 Excavated earth spillway**Plan view of earth spillways****Profile along centerline****Definition of terms:** H_p = depth of water in reservoir above crest L = length of level portion min. 25 ft b = bottom width of spillway S_o = slope for exit channel S_e = slope of inlet channel**Cross section of level portion**

Table 11 Depth of flow (H_p) and slope range at retardance values for various discharges, velocities, and crest lengths

	Maximum velocity	Discharge	H_p				Slope	
			L				Min.	Max.
			25	50	100	200		
	(ft/s)	(ft ³ /s/ft)	(ft)	(ft)	(ft)	(ft)	(%)	(%)
Retardance A	3	3	2.3	2.5	2.7	3.1	1	11
	4	4	2.3	2.5	2.8	3.1	1	12
	4	5	2.5	2.6	2.9	3.2	1	7
	5	6	2.6	2.7	3.0	3.3	1	9
	6	7	2.7	2.8	3.1	3.5	1	12
	7	10	3.0	3.2	3.4	3.8	1	9
	8	12.5	3.3	3.5	3.7	4.1	1	10
Retardance B	2	1	1.2	1.4	1.5	1.8	1	12
	2	1.25	1.3	1.4	1.6	1.9	1	7
	3	1.5	1.3	1.5	1.7	1.9	1	12
	3	2	1.4	1.5	1.7	1.9	1	8
	4	3	1.6	1.7	1.9	2.2	1	9
	5	4	1.8	1.9	2.1	2.4	1	8
	6	5	1.9	2.1	2.3	2.5	1	10
	7	6	2.1	2.2	2.4	2.7	1	11
8	7	2.2	2.4	2.6	2.9	1	12	
Retardance C	2	0.5	0.7	0.8	0.9	1.1	1	6
	2	1	0.9	1.0	1.2	1.3	1	3
	3	1.25	0.9	1.0	1.2	1.3	1	6
	4	1.5	1.0	1.1	1.2	1.4	1	12
	4	2	1.1	1.2	1.4	1.6	1	7
	5	3	1.3	1.4	1.6	1.8	1	6
	6	4	1.5	1.6	1.8	2.0	1	12
	8	5	1.7	1.8	2.0	2.2	1	12
	9	6	1.8	2.0	2.1	2.4	1	12
	9	7	2.0	2.1	2.3	2.5	1	10
10	7.5	2.1	2.2	2.4	2.6	1	12	
Retardance D	2	0.5	0.6	0.7	0.8	0.9	1	6
	3	1	0.8	0.9	1.0	1.1	1	6
	3	1.25	0.8	0.9	1.0	1.2	1	4
	4	1.25	0.8	0.9	1.0	1.2	1	10
	4	2	1.0	1.1	1.3	1.4	1	4
	5	1.5	0.9	1.0	1.2	1.3	1	12
	5	2	1.0	1.2	1.3	1.4	1	9
	5	3	1.2	1.3	1.5	1.7	1	4
	6	2.5	1.1	1.2	1.4	1.5	1	11
	6	3	1.2	1.3	1.5	1.7	1	7
	7	3	1.2	1.3	1.5	1.7	1	12
	7	4	1.4	1.5	1.7	1.9	1	7
	8	4	1.4	1.5	1.7	1.9	1	12
	8	5	1.6	1.7	1.9	2.0	1	8
	10	6	1.8	1.9	2.0	2.2	1	12

Table 11 Depth of flow (H_p) and slope range at retardance values for various discharges, velocities, and crest lengths—Continued.

	Maximum velocity (ft/s)	Discharge (ft ³ /s/ft)	H_p				Slope	
			L				Min.	Max.
			25 (ft)	50 (ft)	100 (ft)	200 (ft)	(%)	(%)
Retardance E	2	0.5	0.5	0.5	0.6	0.7	1	2
	3	0.5	0.5	0.5	0.6	0.7	1	9
	3	1	0.7	0.7	0.8	0.9	1	3
	4	1	0.7	0.7	0.8	0.9	1	6
	4	1.25	0.7	0.8	0.9	1.0	1	5
	5	1	0.7	0.7	0.8	0.9	1	12
	5	2	0.9	1.0	1.1	1.2	1	4
	6	1.5	0.8	0.9	1.0	1.1	1	12
	6	2	0.9	1.0	1.1	1.2	1	7
	6	3	1.2	1.2	1.3	1.5	1	4
	7	2	0.9	1.0	1.1	1.2	1	12
	7	3	1.2	1.2	1.3	1.5	1	7
	8	3	1.2	1.2	1.3	1.5	1	10
	8	4	1.4	1.4	1.5	1.7	1	6
	10	4	1.4	1.4	1.5	1.7	1	12

Pipes through the dam

Pipe spillways—Protect the vegetation in earth spillway channels against saturation from spring flow or low flows that may continue for several days after a storm. A pipe placed under or through the dam provides this protection. The crest elevation of the entrance should be 12 inches or more below the top of the control section of the auxiliary spillway.

The pipe should be large enough to discharge flow from springs, snowmelt, or seepage. It should also have enough capacity to discharge prolonged surface flow following an intense storm. This rate of flow generally is estimated. If both spring flow and prolonged surface flow can be expected, the pipe should be large enough to discharge both.

Drop inlet and hood inlet pipe spillways are commonly used for ponds.

Drop-inlet pipe spillway—A drop-inlet consists of a pipe barrel (fig. 22) located under the dam and a riser connected to the upstream end of the barrel. This riser can also be used to drain the pond if a suitable valve or gate is attached at its upstream end (fig. 23).

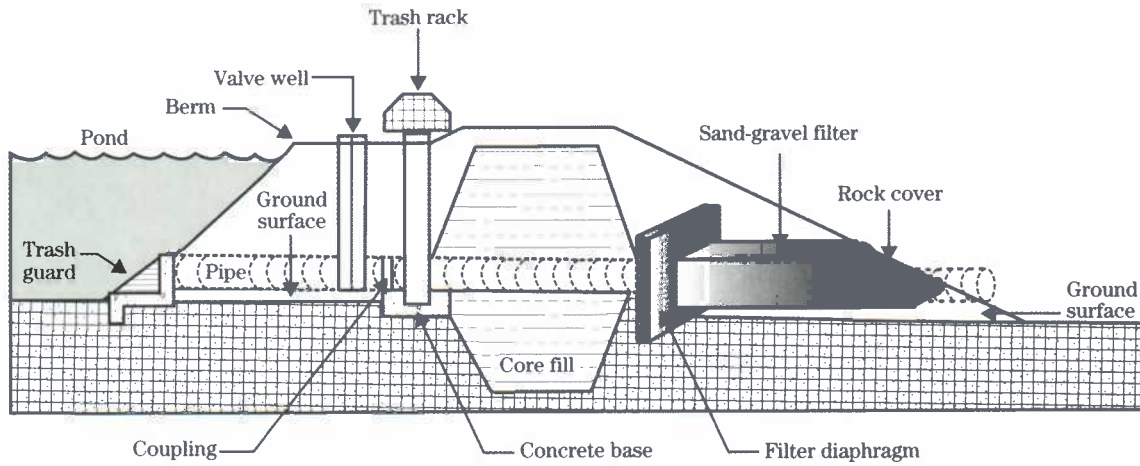
With the required discharge capacity determined, use table 12 or 13 to select an adequate pipe size for the barrel and riser. Table 12 is for barrels of **smooth pipe**, and table 13 is for barrels of **corrugated metal pipe**. The diameter of the riser must be somewhat larger than the diameter of the barrel if the tube is to flow full. Recommended combinations of barrel and riser diameters are shown in the tables. In these tables the total head is the vertical distance between a point 1 foot above the riser crest and the centerline of the barrel at its outlet end. Because pipes of small diameter are easily clogged by trash and rodents, no pipe smaller than 6 inches in diameter should be used for the barrel.

Figure 22 Drop-inlet pipe spillway with antiseep collar



Figure 23 Drop-inlet pipe spillways

(a) With sand-gravel filter



(b) With antiseep collar

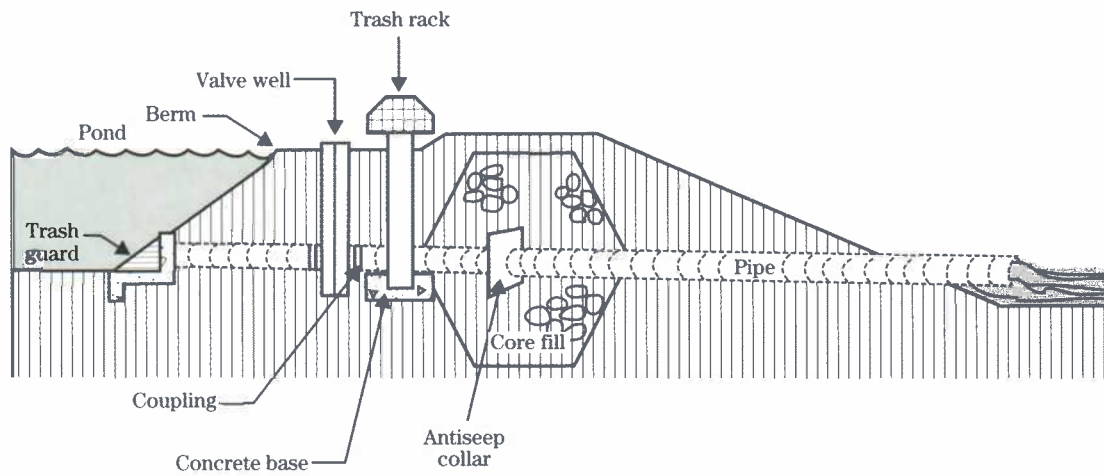


Table 12 Discharge values for **smooth pipe** drop inlets ^{1/}

Total head (ft)	Ratio of barrel diameter to riser diameter (in)					
	6:8 (ft ³ /s)	8:10 (ft ³ /s)	10:12 (ft ³ /s)	12:15 (ft ³ /s)	15:24 (ft ³ /s)	18:36 (ft ³ /s)
6	1.54	3.1	5.3	8.1	13.6	20.6
8	1.66	3.3	5.7	8.9	14.8	22.5
10	1.76	3.5	6.1	9.6	15.8	24.3
12	1.86	3.7	6.5	10.2	16.8	26.1
14	1.94	3.9	6.8	10.7	17.8	27.8
16	2.00	4.0	7.0	11.1	18.6	29.2
18	2.06	4.1	7.2	11.5	19.3	30.4
20	2.10	4.2	7.4	11.8	19.9	31.3
22	2.14	4.3	7.6	12.1	20.5	32.2
24	2.18	4.4	7.8	12.4	21.0	33.0
26	2.21	4.5	8.0	12.6	21.5	33.8

^{1/} Length of pipe barrel used in calculations is based on a dam with a 12-foot top width and 2.5:1 side slopes. Discharge values are based on a minimum head on the riser crest of 12 inches. Pipe flow based on Manning's $n = 0.012$.

Table 13 Discharge values for **corrugated metal pipe** drop inlets ^{1/}

Total head (ft)	Ratio of barrel diameter to riser diameter (in)					
	6:8 (ft ³ /s)	8:10 (ft ³ /s)	10:12 (ft ³ /s)	12:15 (ft ³ /s)	15:21 (ft ³ /s)	18:24 (ft ³ /s)
6	0.85	1.73	3.1	5.1	8.8	14.1
8	0.90	1.85	3.3	5.4	9.4	15.0
10	0.94	1.96	3.5	5.7	9.9	15.9
12	0.98	2.07	3.7	6.0	10.4	16.7
14	1.02	2.15	3.8	6.2	10.8	17.5
16	1.05	2.21	3.9	6.4	11.1	18.1
18	1.07	2.26	4.0	6.6	11.4	18.6
20	1.09	2.30	4.1	6.7	11.7	18.9
22	1.11	2.34	4.2	6.8	11.9	19.3
24	1.12	2.37	4.2	6.9	12.1	19.6
26	1.13	2.40	4.3	7.0	12.3	19.9

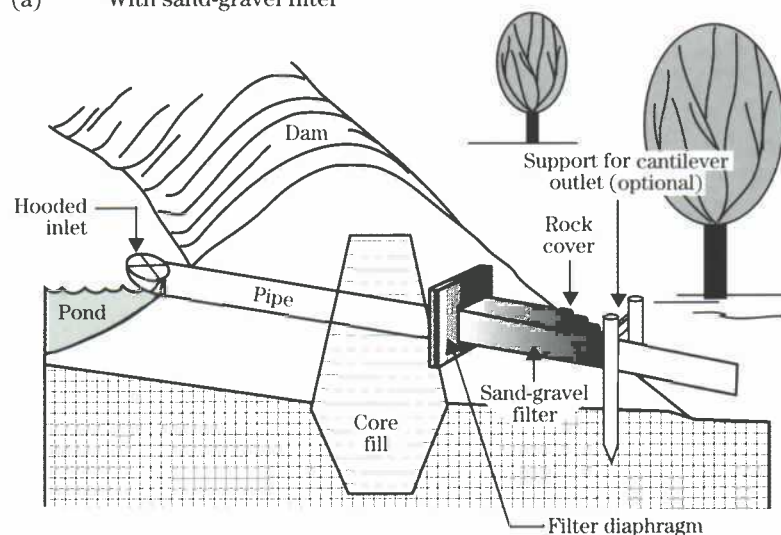
^{1/} Length of pipe barrel used in calculations is based on a dam with a 12-foot top width and 2.5:1 side slopes. Discharge values are based on a minimum head on the riser crest of 12 inches. Pipe flow based on Manning's $n = 0.012$.

Hood-inlet pipe spillway—A hood-inlet consists of a pipe laid in the earthfill (fig. 24). The inlet end of the pipe is cut at an angle to form a hood. An antivortex device, usually metal, is attached to the entrance of the pipe to increase the hydraulic efficiency of the

tube. Typical installations of hood inlets and details of the antivortex device are shown in figure 25. Often a hood-inlet can be built at less cost than a drop-inlet because no riser is needed. The major disadvantage of this kind of pipe spillway is that it cannot be used as a drain.

Figure 24 Dam with hooded inlet pipe spillway

(a) With sand-gravel filter



(b) With antiseep collar

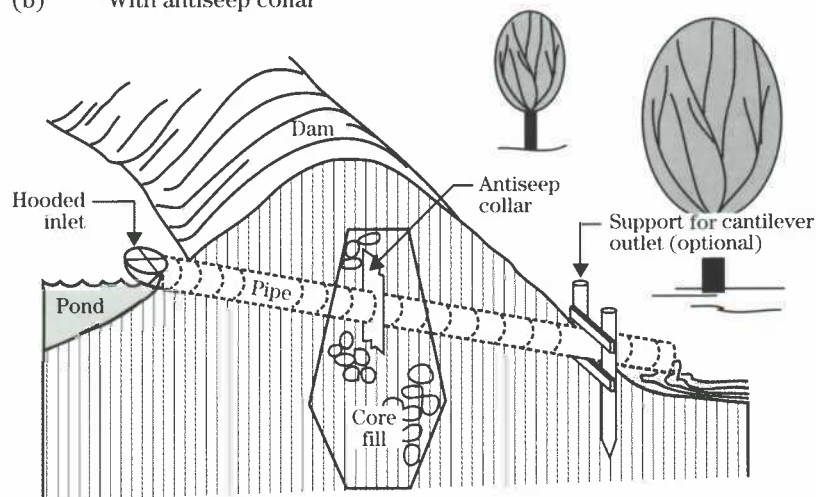
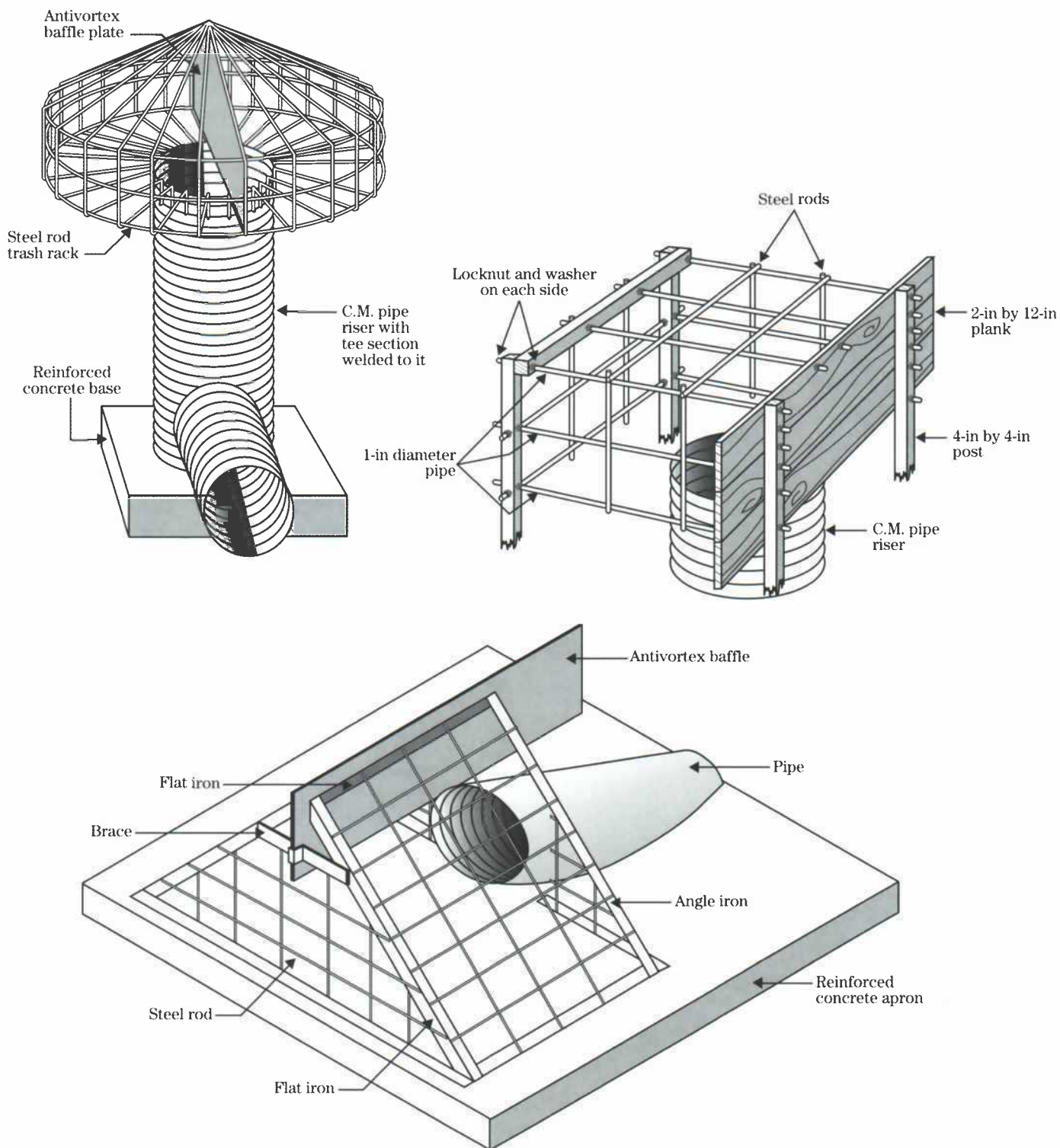


Figure 25 Pipe inlet spillways that have trash rack and antivortex baffle

The required diameter for a hood-inlet pipe can be selected from table 14 or 15 after estimating the discharge capacity, Q , and determining the total head, H . The tables also show the minimum head, h , required above the invert or crest elevation of the pipe entrance. Unless you provide this minimum head, the pipe will not flow full.

Pipe made of cast iron, smooth steel, concrete, plastic, or corrugated metal is suitable for either kind of pipe spillway. All joints must be watertight. A concrete cradle or bedding is needed for concrete pipe to ensure a firm foundation and good alignment of the conduit. Seal the joints of concrete pipe with an approved type of rubber gasket to give them the desired amount of flexibility. For all pipe spillways, use new pipe or pipe so slightly used that it may be considered equivalent to new pipe.

To retard seepage through the embankment along the outside surface of the pipe, compact the fill around the pipe and use a filter and drainage diaphragm around the pipe like that shown in figure 24.

One filter and drainage diaphragm should be used around any structure that extends through the embankment to the downstream slope. The diaphragm should be located downstream of the centerline of a homogeneous embankment or downstream of the cutoff trench. The diaphragm should be a minimum of 3 feet thick and extend around the pipe surface a minimum of 2 times the outside diameter of the pipe ($2D_o$). When a cradle or bedding is used under the pipe, the vertical downward $2D_o$ is measured from the bottom of the cradle or bedding. If bedrock is encountered within the $2D_o$ measurement, the diaphragm should terminate at the bedrock surface. The location

Table 14 Minimum head, h (ft), required above the invert of hood inlets to provide full flow, Q (ft³/s), for various sizes of smooth pipe and values of total head, H ^{1/}

Total head (ft)	Diameter of pipe in inches					
	6	8	10	12	15	18
6	$h = 0.63$ $Q = 1.63$	$h = 0.85$ $Q = 3.0$	$h = 1.04$ $Q = 5.3$	$h = 1.23$ $Q = 8.5$	$h = 1.54$ $Q = 14.0$	$h = 1.82$ $Q = 21.2$
8	$h = 0.65$ $Q = 1.78$	$h = 0.86$ $Q = 3.5$	$h = 1.06$ $Q = 6.0$	$h = 1.27$ $Q = 9.3$	$h = 1.57$ $Q = 15.5$	$h = 1.87$ $Q = 23.3$
10	$h = 0.66$ $Q = 1.93$	$h = 0.87$ $Q = 3.8$	$h = 1.08$ $Q = 6.6$	$h = 1.30$ $Q = 10.2$	$h = 1.60$ $Q = 17.0$	$h = 1.91$ $Q = 25.4$
12	$h = 0.67$ $Q = 2.06$	$h = 0.88$ $Q = 4.1$	$h = 1.09$ $Q = 7.1$	$h = 1.32$ $Q = 10.9$	$h = 1.63$ $Q = 18.3$	$h = 1.94$ $Q = 27.5$
14	$h = 0.67$ $Q = 2.18$	$h = 0.89$ $Q = 4.3$	$h = 1.11$ $Q = 7.5$	$h = 1.33$ $Q = 11.6$	$h = 1.65$ $Q = 19.5$	$h = 1.96$ $Q = 29.4$
16	$h = 0.68$ $Q = 2.28$	$h = 0.90$ $Q = 4.5$	$h = 1.13$ $Q = 7.8$	$h = 1.35$ $Q = 12.2$	$h = 1.67$ $Q = 20.5$	$h = 1.98$ $Q = 31.0$
18	$h = 0.69$ $Q = 2.36$	$h = 0.91$ $Q = 4.7$	$h = 1.14$ $Q = 8.1$	$h = 1.36$ $Q = 12.7$	$h = 1.69$ $Q = 21.4$	$h = 2.00$ $Q = 32.5$
20	$h = 0.69$ $Q = 2.43$	$h = 0.92$ $Q = 4.9$	$h = 1.15$ $Q = 8.4$	$h = 1.37$ $Q = 13.2$	$h = 1.70$ $Q = 22.2$	$h = 2.02$ $Q = 33.9$
22	$h = 0.70$ $Q = 2.50$	$h = 0.93$ $Q = 5.0$	$h = 1.16$ $Q = 8.7$	$h = 1.38$ $Q = 13.6$	$h = 1.71$ $Q = 23.0$	$h = 2.04$ $Q = 35.1$
24	$h = 0.70$ $Q = 2.56$	$h = 0.93$ $Q = 5.1$	$h = 1.16$ $Q = 9.0$	$h = 1.39$ $Q = 14.0$	$h = 1.72$ $Q = 23.7$	$h = 2.05$ $Q = 36.3$
26	$h = 0.71$ $Q = 2.60$	$h = 0.94$ $Q = 5.2$	$h = 1.17$ $Q = 9.3$	$h = 1.40$ $Q = 14.4$	$h = 1.73$ $Q = 24.4$	$h = 2.07$ $Q = 37.5$

^{1/} Length of pipe used in calculations is based on a dam with a 12-foot top width and 2.5:1 side slopes. Pipe flow based on Manning's $n = 0.012$.

of the diaphragm should never result in a minimum soil cover over a portion of the diaphragm measured normal to the nearest embankment surface of less than 2 feet. If this requirement is exceeded, the filter and drainage diaphragm should be moved upstream until the 2-foot minimum is reached. The outlet for the filter and drainage diaphragm should extend around the pipe surface a minimum of 1.5 times the outside diameter of the pipe ($1.5D_o$) that has 1 foot around the pipe being a minimum.

In most cases where the embankment core consists of fine-grained materials, such as sandy or gravely silts and sandy or gravely clay (15 to 85 percent passing the No. 200 sieve), an aggregate conforming to ASTM C-33 fine concrete aggregate is suitable for the filter and drainage diaphragm material. A fat clay or elastic silt

(more than 85 percent passing No. 200 sieve) core requires special design considerations, and an engineer experienced in filter design should be consulted.

Using a filter and drainage diaphragm has many advantages. Some are as follows:

- They provide positive seepage control along structures that extend through the fill.
- Unlike concrete antiseep collars, they do not require curing time.
- Installation is easy with little opportunity for constructed failure. The construction can consist mostly of excavation and backfilling with the filter material at appropriate locations.

Antiseep collars can be used instead of the filter and drainage diaphragm. Antiseep collars have been used

Table 15 Minimum head, h (ft), required above the invert of hood inlets to provide full flow, Q (ft^3/s), for various sizes of corrugated pipe and values of total head, H ^{1/}

Total head (ft)	Diameter of pipe in inches					
	6	8	10	12	15	18
6	$h = 0.59$	$h = 0.78$	$h = 0.97$	$h = 1.17$	$h = 1.46$	$h = 1.75$
	$Q = 0.92$	$Q = 1.9$	$Q = 3.3$	$Q = 5.3$	$Q = 9.1$	$Q = 14.5$
8	$h = 0.59$	$h = 0.79$	$h = 0.98$	$h = 1.18$	$h = 1.48$	$h = 1.77$
	$Q = 1.00$	$Q = 2.1$	$Q = 3.6$	$Q = 5.8$	$Q = 10.0$	$Q = 16.0$
10	$h = 0.60$	$h = 0.79$	$h = 0.99$	$h = 1.19$	$h = 1.49$	$h = 1.79$
	$Q = 1.06$	$Q = 2.2$	$Q = 3.9$	$Q = 6.3$	$Q = 10.9$	$Q = 17.3$
12	$h = 0.60$	$h = 0.80$	$h = 1.00$	$h = 1.20$	$h = 1.50$	$h = 1.80$
	$Q = 1.12$	$Q = 2.3$	$Q = 4.2$	$Q = 6.7$	$Q = 11.6$	$Q = 18.5$
14	$h = 0.61$	$h = 0.81$	$h = 1.01$	$h = 1.21$	$h = 1.51$	$h = 1.82$
	$Q = 1.18$	$Q = 2.4$	$Q = 4.4$	$Q = 7.1$	$Q = 12.2$	$Q = 19.6$
16	$h = 0.61$	$h = 0.81$	$h = 1.01$	$h = 1.21$	$h = 1.52$	$h = 1.82$
	$Q = 1.22$	$Q = 2.5$	$Q = 4.6$	$Q = 7.4$	$Q = 12.7$	$Q = 20.5$
18	$h = 0.61$	$h = 0.81$	$h = 1.02$	$h = 1.22$	$h = 1.53$	$h = 1.83$
	$Q = 1.26$	$Q = 2.6$	$Q = 4.8$	$Q = 7.6$	$Q = 13.2$	$Q = 21.3$
20	$h = 0.62$	$h = 0.82$	$h = 1.03$	$h = 1.23$	$h = 1.54$	$h = 1.85$
	$Q = 1.30$	$Q = 2.7$	$Q = 4.9$	$Q = 7.8$	$Q = 13.7$	$Q = 21.9$
22	$h = 0.62$	$h = 0.83$	$h = 1.03$	$h = 1.24$	$h = 1.55$	$h = 1.86$
	$Q = 1.33$	$Q = 2.8$	$Q = 5.0$	$Q = 8.0$	$Q = 14.1$	$Q = 22.5$
24	$h = 0.63$	$h = 0.83$	$h = 1.04$	$h = 1.25$	$h = 1.56$	$h = 1.88$
	$Q = 1.35$	$Q = 2.8$	$Q = 5.1$	$Q = 8.2$	$Q = 14.5$	$Q = 23.0$
26	$h = 0.63$	$h = 0.84$	$h = 1.05$	$h = 1.26$	$h = 1.58$	$h = 1.89$
	$Q = 1.37$	$Q = 2.9$	$Q = 5.2$	$Q = 8.3$	$Q = 14.7$	$Q = 23.4$

^{1/} Length of pipe used in calculations is based on a dam with a 12-foot top width and 2.5:1 side slopes. Pipe flow based on Manning's $n = 0.025$.

with pipe spillways for many years. More fabricated materials are required for this type of installation. Both types of seepage control are acceptable; in either case, proper installation is imperative.

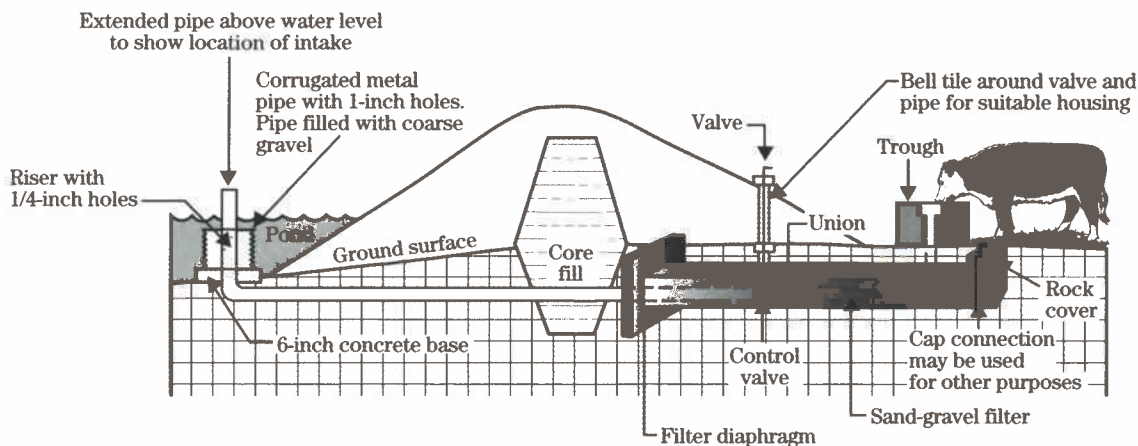
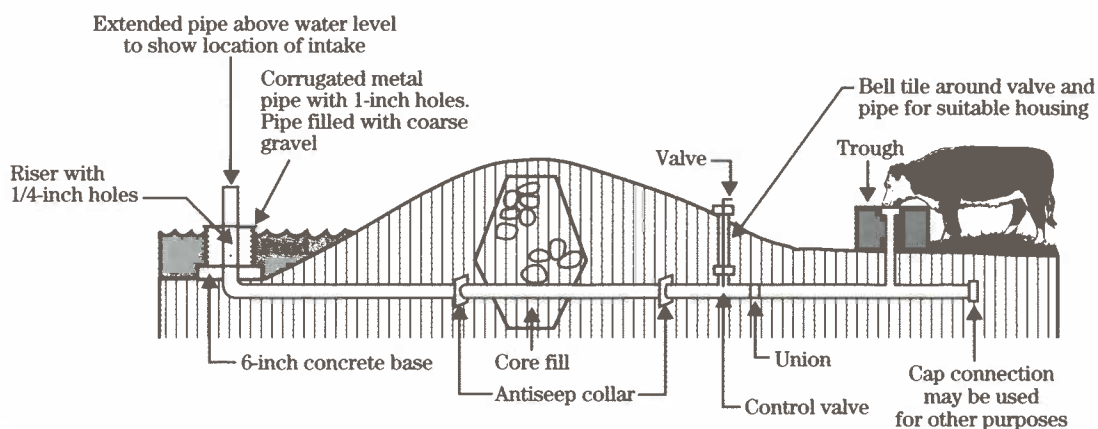
If an antiseep collar is used, it should extend into the fill a minimum of 24 inches perpendicular to the pipe. If the dam is less than 15 feet high, one antiseep collar at the centerline of the fill is enough. For higher dams, use two or more collars equally spaced between the fill centerline and the upstream end of the conduit when a hood-inlet pipe is used. If a drop-inlet pipe is used, the antiseep collars should be equally spaced between the riser and centerline of the fill.

Use trash racks to keep pipes from clogging with trash and debris. Of the many kinds of racks that have been used, the three shown in figure 25 have proved the most successful.

Extend the pipe 6 to 10 feet beyond the downstream toe of the dam to prevent damage by the flow of water from the pipe. For larger pipes, support the extension with a timber brace.

Drainpipes—Some state regulatory agencies require that provision be made for draining ponds completely or for fluctuating the water level to eliminate breeding places for mosquitoes. Whether compulsory or not, provision for draining a pond is desirable and recommended. It permits good pond management for fish production and allows maintenance and repair without cutting the fill or using siphons, pumps, or other devices to remove the water. Install a suitable gate or other control device and extend the drainpipe to the upstream toe of the dam to drain the pond.

Water-supply pipes—Provide a water-supply pipe that runs through the dam if water is to be used at some point below the dam for supplying a stockwater trough, for irrigation, or for filling an orchard spray tank (fig. 26). This pipe is in addition to the principal spillway. A water-supply pipe should be rigid and have watertight joints, a strainer at its upper end, and a valve at its outlet end. For a small rate of flow, such as that needed to fill stockwater troughs, use steel or plastic pipe that is 1-1/2 inches in diameter. For a larger rate of flow, such as that needed for irrigation, use steel, plastic, or concrete pipe of larger diameter. Water-supply pipes also should have watertight joints and antiseep collars or a filter and drainage diaphragm.

Figure 26 Water is piped through the dam's drainpipe to a stockwater trough**(a) Pipe with sand-gravel filter****(b) Pipe with antiseep collars**

Planning an earthfill dam

Foundations—You can build a safe earthfill dam on almost any foundation if you thoroughly investigate the foundation and adapt the design and construction to the conditions. Some foundation conditions require expensive construction measures that cannot be justified for small ponds.

The most satisfactory foundation consists of soil underlain at a shallow depth by a thick layer of relatively impervious consolidated clay or sandy clay. If a suitable layer is at or near the surface, no special measures are needed except removing the topsoil and scarifying or disking to provide a bond with the material in the dam.

If the foundation is sand or a sand-gravel mixture and there is no impervious clay layer at a depth that can be reached economically with available excavating equipment, an engineer should design the dam. Although such foundations may be stable, corrective measures are needed to prevent excessive seepage and possible failure. A foundation, consisting of or underlain by a highly plastic clay or unconsolidated material requires careful investigation and design to obtain stability. If the foundation consists of such materials, consult an engineer.

Water impounded on a bedrock foundation seldom gives cause for concern unless the rock contains seams, fissures, or crevices through which water may escape at an excessive rate. Where rock is in the foundation, investigate the nature of the rock carefully.

Cutoffs—If the dam's foundation is overlain by alluvial deposits of pervious sands and gravels at or near the surface and rock or clay at a greater depth, seepage in the pervious stratum must be reduced to prevent possible failure of the dam by piping. To prevent excessive seepage, you need a cutoff to join the impervious stratum in the foundation with the base of the dam.

The most common kind of cutoff is made of compacted clayey material. A trench is excavated along the centerline of the dam deep enough to extend well into the impervious layer (fig. 27). This trench extends into and up the abutments of the dam as far as there is any pervious material that might allow seepage. The bottom of the trench should be no less than 8 feet wide (or the bulldozer blade width, whichever is

greater), and the sides no steeper than 1.5:1. Fill the trench with successive thin layers (9-inch maximum) of clay or sandy clay material. Compact each layer thoroughly at near-optimum moisture conditions before placing the next layer. The moisture content is adequate for compaction when the material can be formed into a firm ball that sticks together and remains intact when the hand is vibrated violently and no free water appears.

Top width and alignment—For dams less than 10 feet high, a conservative minimum top width is 6 feet. As the height of the dam increases, increase the top width. The recommended minimum top width for earth embankments of various heights is:

<u>Height of dam</u> (ft)	<u>Minimum top width</u> (ft)
Under 10	6
11 to 14	8
15 to 19	10
20 to 24	12
25 to 34	14

If the top of the embankment is to be used for a roadway, provide for a shoulder on each side of the roadway to prevent raveling. The top width should be at least 16 feet. In some situations a curved dam align-

Figure 27 A core trench is cut on the centerline of a dam



ment is more desirable than a straight alignment. Curvature can be used to retain existing landscape elements, reduce the apparent size of the dam, blend the dam into surrounding natural landforms, and provide a natural-appearing shoreline.

Side slopes—The side slopes of a dam depend primarily on the stability of the fill and on the strength and stability of the foundation material. The more stable the fill material, the steeper the side slopes. Unstable materials require flatter side slopes. Recommended slopes for the upstream and downstream faces of dams built of various materials are shown in table 16.

For stability, the slopes should not be steeper than those shown in table 16, but they can be flatter as long as they provide surface drainage. The side slopes need not be uniform, but can be shaped to blend with the surrounding landforms (fig. 28).

Finish-grading techniques used to achieve a smooth landform transition include slope rounding and slope warping. Slope rounding is used at the top and bottom of cuts or fills and on side slope intersections. Slope warping is used to create variety in the horizontal and vertical pitch of finished slopes (fig. 29). Additional fill can be placed on the backslope and abutments of the dam, if needed, to achieve this landform transition.

Freeboard—Freeboard is the additional height of the dam provided as a safety factor to prevent overtopping by wave action or other causes. It is the vertical distance between the elevation of the water surface in the pond when the spillway is discharging at designed depth and the elevation of the top of the dam after all

settlement. If your pond is less than 660 feet long, provide a freeboard of no less than 1 foot. The minimum freeboard is 1.5 feet for ponds between 660 and 1,320 feet long, and is 2 feet for ponds up to a half mile long. For longer ponds an engineer should determine the freeboard.

Settlement allowance—Settlement or consolidation depends on the character of the materials in both the dam and the foundation and on the construction method. To allow for settlement, build earth dams somewhat higher than the design dimensions. If your dam is adequately compacted in thin layers under good moisture conditions, there is no reason to expect any appreciable settlement in the dam itself, but the foundation may settle. For a compacted fill dam on unyielding foundation, settlement is negligible.

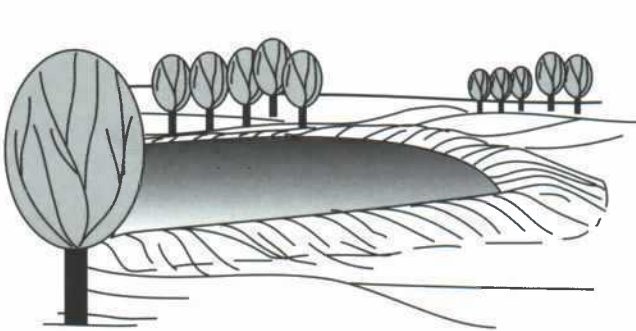
Most foundations are yielding, and settlement may range from 1 to 6 percent of the height of the dam, mainly during construction. The settlement allowance for a rolled-fill dam should be about 5 percent of the designed dam height. In other words, the dam is built 5 percent higher than the designed height. After settlement, the height of the dam will be adequate. Most pond dams less than 20 feet high, however, are not rolled fill. For these dams the total settlement allowance should be about 10 percent.

Estimating the volume of the earthfill—After planning is completed, estimate the number of cubic yards of earthfill required to build the dam. Also estimate excavation yardage in foundation stripping, core trench excavation, and any other significant excavations. This helps predict the cost of the dam

Table 16 Recommended side slopes for earth dams

Fill material	Slope	
	Upstream	Downstream
Clayey sand, clayey gravel, sandy clay, silty sand, silty gravel	3:1	2:1
Silty clay, clayey silt	3:1	3:1

Figure 28 Dam side slopes are curved and shaped to blend with surrounding topography



and serves as a basis for inviting bids and for awarding a construction contract. The estimate of the volume of earthfill should include

- volume in the dam itself including the allowance for settlement,
- volume required to backfill the cutoff trench,
- volume required to backfill stream channels or holes in the foundation area, and
- any other volume of earthfill the contractor is required to move.

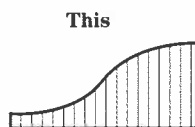
Volume estimates for dams generally are made of the required number of cubic yards of earthfill in place. Probably the most efficient method of estimating the volume of earthfill is the sum-of-end-area method. The ground surface elevations at all points along the centerline of the dam where the slope changes significantly are established by the centerline profile. With the settled top elevation of the dam established, you

can obtain the settle fill height at each of these points by subtracting the ground surface elevation from the settle top elevation. With the fill heights, side slopes, and top width established, find the end areas at each of these stations along the centerline in table 17.

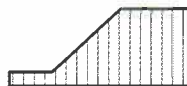
For example, assume that a dam has slopes of 3:1 on both upstream and downstream sides and a top width of 12 feet. For a point along the centerline where the fill is 15 feet high, the table shows that the end area at that point is 675 plus 180, or 855 square feet. The number of cubic yards of fill between two points on the centerline of the dam is equal to the sum of the end areas at those two points multiplied by the distance between these points and divided by 54. The total volume of earthfill in the dam is the sum of all such segments. A sample volume estimate illustrating the use of the sum-of-end-areas method is shown in table 18.

Figure 29 Finished grading techniques

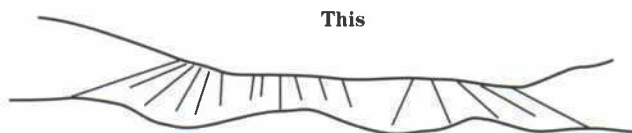
(a) Slope rounding



Not this



(b) Slope warping



Not this



Table 17 End areas in square feet of embankment sections for different side slopes and top widths ^{1/}

Fill height (ft)	----- Side slopes -----					----- Top width (ft) -----				
	2.5:1	2.5:1	3:1	3.5:1	4:1	8	10	12	14	16
	2.5:1	3:1	3:1	3.5:1	4:1					
	2:1	2:1	2.5:1	3:1	3:1					
	3:1	3.5:1	3.5:1	4:1	5:1					
1.0	3	3	3	4	4	8	10	12	14	16
1.2	4	4	4	5	6	10	12	14	17	19
1.4	5	5	6	7	8	11	14	17	20	22
1.6	6	7	8	9	10	13	16	19	22	26
1.8	8	9	10	11	13	14	18	22	25	29
2.0	10	11	12	14	16	16	20	24	28	32
2.2	12	13	15	17	19	18	22	27	31	35
2.4	14	16	17	20	23	19	24	29	34	39
2.6	17	19	20	24	27	21	26	31	36	42
2.8	20	22	23	27	31	22	28	34	39	45
3.0	22	25	27	32	36	24	30	36	42	48
3.2	26	28	31	36	41	26	32	38	45	51
3.4	29	32	35	40	46	27	34	41	47	55
3.6	32	36	39	45	52	29	36	43	50	58
3.8	36	40	43	50	58	30	38	46	53	61
4.0	40	44	48	56	64	32	40	48	56	64
4.2	44	49	53	62	71	34	42	50	59	67
4.4	48	53	58	68	77	35	44	53	61	71
4.6	53	58	63	74	85	37	46	55	64	74
4.8	57	63	69	81	92	38	48	57	67	77
5.0	62	69	75	87	100	40	50	60	70	80
5.2	67	74	81	94	108	42	52	62	73	83
5.4	73	80	87	102	117	43	54	65	75	87
5.6	78	86	94	110	125	45	56	67	78	90
5.8	84	93	101	118	135	46	58	69	81	93
6.0	90	99	108	126	144	48	60	72	84	96
6.2	96	106	115	135	154	50	62	74	87	99
6.4	102	113	123	143	164	51	64	77	89	103
6.6	109	120	131	152	174	53	66	79	92	106
6.8	116	128	139	162	185	54	68	81	95	109
7.0	123	135	147	172	196	56	70	84	98	112
7.2	130	143	156	182	207	58	72	86	101	115
7.4	138	152	165	193	219	59	74	89	103	119
7.6	145	159	174	203	231	61	76	91	106	122
7.8	153	168	183	214	243	62	78	93	109	125
8.0	160	176	192	224	256	64	80	96	112	128
8.2	169	185	202	235	269	66	82	98	115	131
8.4	177	194	212	247	282	67	84	101	117	135
8.6	186	204	222	259	296	69	86	103	120	138
8.8	194	213	232	271	310	70	88	105	123	141

See footnote at end of table.

Table 17 End areas in square feet of embankment sections for different side slopes and top widths ^{1/}—Continued.

Fill height (ft)	----- Side slopes -----					----- Top width (ft) -----				
	2.5:1	2.5:1	3:1	3.5:1	4:1	8	10	12	14	16
	2.5:1	3:1	3:1	3.5:1	4:1					
	2:1	2:1	2.5:1	3:1	3:1					
	3:1	3.5:1	3.5:1	4:1	5:1					
9.0	203	223	243	283	324	72	90	108	126	144
9.2	212	233	254	296	339	74	92	110	129	147
9.4	222	244	266	310	353	75	94	113	131	151
9.6	231	254	277	323	369	77	96	115	134	154
9.8	241	265	289	337	384	78	98	117	137	157
10.0	250	275	300	350	400	80	100	120	140	160
10.2	260	286	313	364	416		102	122	143	163
10.4	271	298	325	379	433		104	125	145	167
10.6	281	309	338	394	449		106	127	148	170
10.8	292	321	350	409	467		108	129	151	173
11.0	302	333	363	424	484		110	132	154	176
11.2	313	344	376	440	502		112	134	157	179
11.4	325	357	390	456	520		114	137	159	183
11.6	336	370	404	472	538		116	139	162	186
11.8	348	383	418	488	557		118	141	165	189
12.0	360	396	432	504	576		120	144	168	192
12.2	372	409	447	522	595		122	146	171	195
12.4	385	424	462	539	615		124	149	173	199
12.6	397	437	477	557	635		126	151	176	202
12.8	410	451	492	574	655		128	153	179	205
13.0	422	465	507	592	676		130	156	182	208
13.2	436	479	523	610	697		132	158	185	211
13.4	449	494	539	629	718		134	161	187	215
13.6	463	509	555	648	740		136	163	190	218
13.8	476	523	571	667	762		138	166	193	221
14.0	490	539	588	686	784		140	168	196	224
14.2	505	555	605	706	807		142	170	199	227
14.4	519	570	622	726	829		144	173	202	230
14.6	534	586	639	746	853		146	175	204	234
14.8	548	602	657	767	876		148	178	207	237
15.0	563	619	675	788	900		150	180	210	240
15.2	578	635	693	809	924		152	182	213	243
15.4	594	653	711	830	949		154	185	216	246
15.6	609	669	730	852	973		156	187	218	250
15.8	625	687	749	874	999		158	190	221	253
16.0	640	704	768	896	1,024		160	192	224	256
16.2	656	722	787	919	1,050			194	227	259
16.4	673	740	807	942	1,076			197	230	262
16.6	689	758	827	965	1,102			199	232	266
16.8	706	776	847	988	1,129			202	235	269
17.0	723	795	867	1,012	1,156			204	238	272

See footnote at end of table.

Table 17 End areas in square feet of embankment sections for different side slopes and top widths ^{1/}—Continued.

Fill height (ft)	----- Side slopes -----					----- Top width (ft) -----				
	2.5:1	2.5:1	3:1	3.5:1	4:1	8	10	12	14	16
	2.5:1	3:1	3:1	3.5:1	4:1					
	2:1	2:1	2.5:1	3:1	3:1					
	3:1	3.5:1	3.5:1	4:1	5:1					
17.2	740	814	888	1,036	1,183			206	241	275
17.4	757	833	909	1,060	1,211			209	244	278
17.6	774	852	930	1,084	1,239			211	246	282
17.8	792	871	951	1,109	1,267			214	249	285
18.0	810	891	972	1,134	1,296			216	252	288
18.2	828	911	994	1,160	1,325			218	255	291
18.4	846	931	1,016	1,186	1,354			221	258	294
18.6	865	951	1,038	1,212	1,384			223	260	298
18.8	884	972	1,060	1,238	1,414			226	263	301
19.0	903	993	1,083	1,264	1,444			228	266	304
19.2	922	1,014	1,106	1,291	1,475			230	269	307
19.4	941	1,035	1,129	1,318	1,505			233	272	310
19.6	960	1,056	1,152	1,345	1,537			235	274	314
19.8	980	1,078	1,176	1,372	1,568			238	277	317
20.0	1,000	1,100	1,200	1,400	1,600			240	280	320
20.2	1,020	1,122	1,224	1,428	1,632			242	283	323
20.4	1,040	1,144	1,248	1,457	1,665			245	286	326
20.6	1,061	1,167	1,273	1,486	1,697			247	288	330
20.8	1,082	1,190	1,298	1,515	1,731			250	291	333
21.0	1,103	1,213	1,323	1,544	1,764			252	294	336
21.2	1,124	1,236	1,348	1,574	1,798			254	297	339
21.4	1,145	1,254	1,374	1,604	1,832			257	300	342
21.6	1,166	1,283	1,400	1,634	1,866			259	302	346
21.8	1,188	1,307	1,426	1,664	1,901			262	305	349
22.0	1,210	1,331	1,452	1,694	1,936			264	308	352
22.2	1,232	1,356	1,479	1,725	1,971			266	311	355
22.4	1,254	1,380	1,506	1,756	2,007			269	314	358
22.6	1,277	1,405	1,533	1,788	2,043			271	316	362
22.8	1,300	1,430	1,560	1,820	2,079			274	319	365
23.0	1,323	1,455	1,587	1,852	2,116			276	322	368

^{1/} To find the end area for any fill height, add square feet given under staked side slopes to that under the top width for total section. Example: 6.4-foot 3:1 front and back slopes, 14-foot top width —123 plus 89, or 212 square feet for the section. Any combination of slopes that adds to 5, 6, or 7 may be used. A combination of 3.5:1 front and 2.5:1 back gives the same results as 3:1 front and back.

Table 18 Volume of material needed for the earthfill

Station (ft)	Ground elevation (ft)	Fill height ^{1/} (ft)	End area ^{2/} (ft ²)	Sum of end areas (ft ²)	Distance (ft)	Double volume (ft ³)
0 + 50	35.0	0	0	44	18	792
+ 68	32.7	2.3	44			
1 + 00	25.9	9.1	357	401	32	12,832
+ 37	21.5	13.5	709	1,066	37	39,442
+ 53	20.0	15.0	855	1,564	16	25,024
+ 75	19.8	15.2	875	1,730	22	38,060
2 + 00	19.5	15.5	906	1,781	25	44,525
+ 19	20.3	14.7	824	1,730	19	32,870
+ 32	20.3	14.7	824	1,648	13	21,424
+ 36	18.8	16.2	981	1,805	4	7,220
+ 40	18.2	16.8	1,049	2,030	4	8,120
+ 43	18.5	16.5	1,015	2,064	3	6,192
+ 46	19.6	15.4	896	1,911	3	5,733
+ 59	19.8	15.2	875	1,771	13	23,023
3 + 00	20.8	14.2	775	1,650	41	67,650
+ 35	27.7	7.3	248	1,023	35	35,805
+ 60	31.6	3.4	76	324	25	8,100
3 + 96	35.0	.0	0	76	36	2,736
Total						379,548 ^{3/}

1/ Elevation of top of dam without allowance for settlement.

2/ End areas based on 12-foot top width and 3:1 slopes on both sides.

3/ Divide double volume in cubic feet by 54 to obtain volume in cubic yards; for example,

$$\frac{379,548}{54} = 7,029 \text{ yd}^3$$

Allowance for settlement (10%) = 703 yd³

Total volume = 7.732 yd³.

The sample volume estimate of 7,732 cubic yards includes only the volume of earth required to complete the dam itself. Estimate the volume of earth required to backfill the core trench, old stream channels, and other required excavation and add it to the estimate for the dam. Also include an estimate of additional fill to be placed on the backslope and abutments. For example, assume that, in addition to the volume shown in table 18, there is a cutoff trench to be backfilled. The dimensions of the trench are:

Average depth = 4.0 ft
 Bottom width = 8.0 ft
 Side slopes = 1.5:1
 Length = 177 ft

Compute the volume of backfill as follows:

$$\text{End area} = \left[w + (z \times d) \right] d \quad [\text{Eq. 4}]$$

$$\text{Volume} = \frac{(\text{End area} \times l)}{27} \quad [\text{Eq. 5}]$$

where:

d = average depth
 w = bottom width
 l = length
 z = side slopes

$$\text{End area} = [8 + (1.5 \times 4)]4 = 56 \text{ ft}^2$$

$$\text{Volume} = \frac{56 \times 177}{27} = 367 \text{ yd}^3$$

Add this to the volume required for the dam and the total volume is 7,732 plus 367, or 8,099 cubic yards. This 8,099 cubic yards represents the required compacted volume. To account for shrinkage resulting from compaction, a minimum of 1.5 times this amount is generally necessary to have available in the borrow areas and required excavations. In this example you need a minimum of 12,148 cubic yards available to construct the dam.

Drawings and specifications—Record on the engineering drawings all planning information that would affect the construction of the dam. These drawings should show all elevations and dimensions of the dam, the dimensions and extent of the cutoff trench and

other areas requiring backfill, the location and dimensions of the principal spillway and other planned appurtenances, and any other pertinent information. The drawings should also include a list of the estimated quantity and kind of building materials required. The construction and material specifications state the extent and type of work, site specific details, material quality, and requirements for prefabricated materials.

Observe all land disturbance laws by including temporary protective measures during construction to minimize soil erosion and sedimentation.

Unless you have all the necessary equipment, you will need to employ a contractor to build the pond. You may wish to receive bids from several contractors to be sure that you are getting the job done at the lowest possible cost. A set of drawings and specifications shows what is to be done. This provides a basis for contractors to bid on the proposed work, allows fair competition **among** bidders, and states the conditions under which the work is to be done. The specifications should

- give all the information not shown on the drawings that is necessary to define what is to be done,
- prescribe how the work is to be done if such direction is required,
- specify the quality of material and workmanship required, and
- define the method of measurement and the unit of payment for the various items of work that constitute the whole job.

Construction work of the quality and standards desired will not result unless there is a clear understanding of these requirements between the owner and the contractor. For these reasons specifications should be prepared for all ponds for which the owners award the construction contracts.

Assistance in preparing drawings and specifications is available from your local soil conservation district, NRCS specialists, or private consultants.

Staking for construction

Each job must be adequately and clearly staked before construction is started. Staking transmits the information on the drawings to the job site. This information locates the work and provides the lines, grade, and elevations required for construction in accordance with the drawings. Consider the contractor's wishes in staking so that he can make the most effective use of the stakes. The quality and appearance of the completed job reflect the care used in staking. The staking should be done by an engineer or other qualified person.

The areas to be cleared generally consist of the dam site, the auxiliary spillway site, the borrow area, and the area over which water is to be impounded. Mark each area clearly with an adequate number of stakes. In the pond area, locate the proposed water line with a level and surveying rod. This provides a base line from which clearing limits can be established.

To locate the dam, set stakes along its centerline at intervals of 100 feet or less. (Generally this has been done during the initial planning survey.) Then set the fill and slope stakes upstream and downstream from the centerline stakes to mark the points of intersection of the side slopes with the ground surface and to mark the work area limits of construction. These stakes also establish the height of the dam.

To locate the earth auxiliary spillway, first stake the centerline and then set cut and slope stakes along the lines of intersection of the spillway side slopes with the natural ground surface.

If fill material must be obtained from a borrow area, this area must be clearly marked. Set cut stakes to indicate the depth to which the contractor can excavate to stay within the limits of suitable material, as indicated by soil borings. This allows the borrow area to drain readily and marks the limits of construction.

Set stakes to show the centerline location of the principal spillway after foundation preparation has reached the point at which the stakes will not be disturbed. Locate the pipe where it will rest on a firm foundation. Mark the stakes to show cuts from the top of the stakes to the grade elevation of the pipe. With additional stakes, mark the location of the riser, drainage gate, filter and drainage diaphragm or antiseep collars, outlet structures, and other appurtenances.

Building the pond

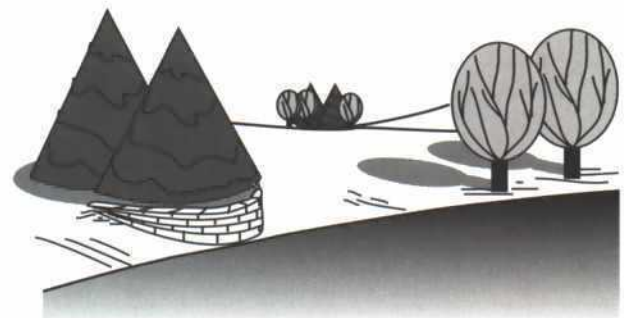
Attention to the details of construction and adherence to the drawings and specifications are as important as adequate investigation and design. Careless and shoddy construction can make an entirely safe and adequate design worthless and cause failure of the dam. Adherence to specifications and prescribed construction methods becomes increasingly important as the size of the structure and the failure hazards increase. Good construction is important regardless of size, and the cost is generally less in the long run than it is for dams built carelessly.

Clearing and grubbing—Clear the foundation area and excavated earth spillway site of trees and brush. In some states this is required by statute. Cut trees and brush as nearly flush with the ground as practicable and remove them and any other debris from the dam site. Should you or your contractor elect to uproot the trees with a bulldozer, you must determine if the tree roots extend into pervious material and if the resultant holes will cause excessive seepage. If so, fill the holes by placing suitable material in layers and compact each layer by compacting or tamping.

All material cleared and grubbed from the pond site, from the earth spillway and borrow areas, and from the site of the dam itself should be disposed of. This can be done by burning, burying under 2 feet of soil, or burying in a disposal area, such as a sanitary landfill.

Minimal clearing conserves site character and minimizes the difficulty and expense of reestablishing vegetation. Confine clearing limits to the immediate construction areas to avoid unnecessary disturbance.

Figure 30 A tree well preserves vegetation



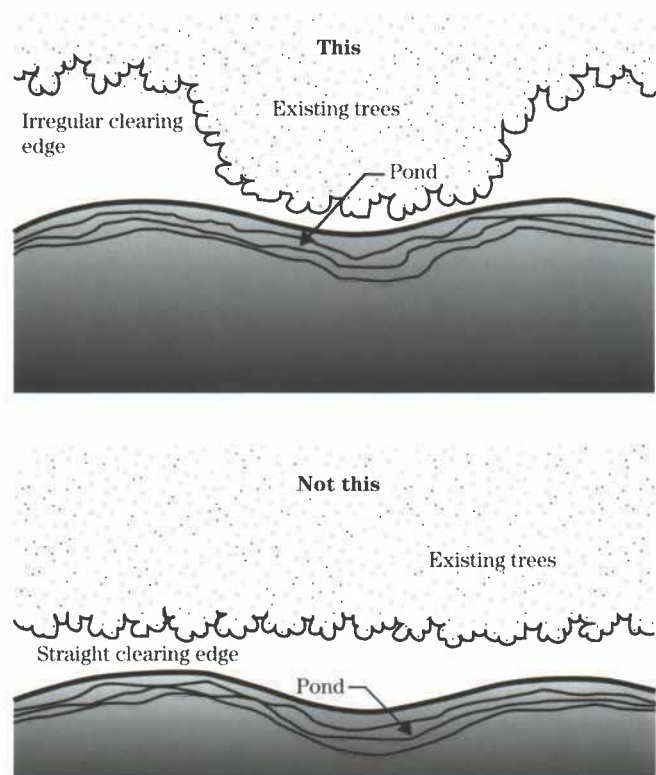
Removing all vegetation within the construction limits is not always necessary. Selected groupings of desirable plants can be kept. Trees and shrubs can often survive a 1- to 2-foot layer of graded fill over their root systems or they can be root-pruned in excavated areas. Tree wells and raised beds can also be used to retain vegetation (fig. 30).

Clearing limits should be irregular to create a natural-appearing edge and open area (fig. 31). Further transition with vegetated surroundings can be accomplished by feathering clearing edges. Density and height of vegetation can be increased progressively from the water's edge to the undisturbed vegetation (fig. 32). Feathering can be accomplished by selective clearing, installation of new plants, or both.

Preparing the foundation—Preparing the foundation includes treating the surface, excavating and backfilling the cutoff trench, and excavating and backfilling existing stream channels. If the foundation has an adequate layer of impervious material at the surface or if it must be blanketed by such a layer, you can eliminate the cutoff trench. Remove sod, boulders, and topsoil from the entire area over which the embankment is to be placed. This operation is best performed by using a tractor-pulled or self-propelled wheeled scraper. The topsoil should be stockpiled temporarily for later use on the site.

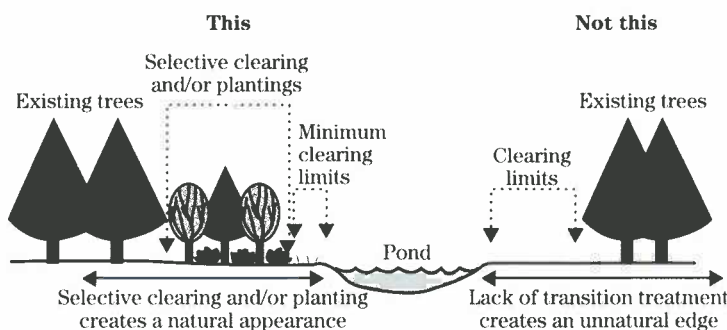
Fill all holes in the foundation area, both natural and those resulting from grubbing operations, with suitable fill material from borrow areas. Use the same method of placement and compaction as used to build the dam. Where necessary use hand or power tampers in areas not readily accessible to other compacting equipment.

Figure 31 Irregular clearing around the pond helps create a natural appearing edge



After filling the holes, thoroughly break the ground surface and turn it to a depth of 6 inches. Roughly level the surface with a disk harrow and then compact it so that the surface materials of the foundation are as well compacted as the subsequent layers of the fill. Dig the cutoff trench to the depth, bottom width, and side slopes shown on the drawings. Often the depths shown on the drawings are only approximate; you

Figure 32 Feathering vegetation at the pond's edge makes a natural transition with existing vegetation



need to inspect the completed trench before backfilling to be sure that it is excavated at least 12 inches into impervious material throughout its entire length.

Material removed from the trench **can** be placed in the downstream third of the dam and compacted in the same manner as the earthfill if the material is free of boulders, roots, organic matter, and other objectionable material.

A dragline excavator and a tractor-pulled or self-propelled wheeled scraper **are** the most satisfactory equipment for excavating cutoff trenches. Before backfilling operations are attempted, pump all free water from the cutoff trench. Some material high in clay content takes up more than twice its own weight of water and becomes a soggy mass. Such clay puddled in the cutoff of a dam may require many years to become stable. Also, in drying it contracts and may leave cracks that can produce a roof of the overlying impervious earthfill section and provide passageways for seepage through the dam.

Backfill the cutoff trench to the natural ground surface with suitable fill material from designated borrow areas. Place the backfill material in thin layers and compact it by the same methods used to build the dam.

Deepen, slope back, and widen stream channels that cross the embankment foundation. This is often necessary to **remove** all stones, gravel, sand, sediment, stumps, roots, organic matter, and any other objectionable material that could interfere with proper bonding of the earthfill with the foundation. Leave side slopes

of the excavated channels no steeper than 3:1 when the channels cross the embankment centerline. If the channels are parallel to the centerline, leave the side slopes no steeper than 1:1. Backfill these channels as recommended for the cutoff trench.

Installing the pipe spillway—Install the pipe, riser (if applicable), filter and drainage diaphragm or anti-seep collars, trash rack, and other mechanical components of the dam to the lines and grades shown on the drawings and staked at the site. To minimize the danger of cracks or openings at the joints caused by unequal settlement of the foundation, place all pipes and other conduits on a firm foundation.

Install pipes and filter and drainage diaphragm or antiseep collars and tamp the selected backfill material around the entire structure before placing the earthfill for the dam. The same procedure applies to all other pipes or conduits.

Excavating the earth spillway—The completed spillway excavation should conform as closely as possible to the lines, grades, bottom width, and side slopes shown on the drawings and staked at the site. Leave the channel bottom transversely level to prevent meandering and the resultant scour within the channel during periods of low flow. If it becomes necessary to fill low places or depressions in the channel bottom **caused** by undercutting the established grade, fill them to the established grade by placing suitable material in 8-inch layers and compacting each layer under the same moisture conditions regardless of the placement in or under the embankment.

Building the dam—Clear the dam and spillway area of trees, brush, stumps, boulders, sod, and rubbish. The sod and topsoil can be stockpiled and used later to cover the dam and spillway (fig. 33). This will help when vegetation is established. Get suitable fill material from previously selected borrow areas and from sites of planned excavation. The material should be free of sod, roots, stones more than 6 inches in diameter, and any material that could prevent the desired degree of compaction. Do not use frozen material or place fill material on frozen foundations.

Selected backfill material should be placed in the core trench and around pipes and antiseep collars, when used. The material should be compacted by hand tamping or manually directed power tampers around pipes. Begin placing fill material at the lowest point and bring it up in horizontal layers, longitudinal to the centerline of dam, approximately 6 inches thick. For fill placement around risers, pipes and filter, and drainage diaphragms, the horizontal layers should be

approximately 4 inches thick. Do not place fill in standing water. The moisture content is adequate for compaction when the material **can** be formed into a firm ball that sticks together and remains intact when the hand is vibrated violently and no free water appears. If the material can be formed into a firm ball that sticks together, the moisture content is adequate for compaction. Laboratory tests of the fill material and field testing of the soil for moisture and compaction may be necessary for large ponds or special conditions.

If the material varies in texture and gradation, use the more impervious (clay) material in the core trench, center, and upstream parts of the dam. Construction equipment can be used to compact earthfill in an ordinary pond dam. Equipment that has rubber tires can be routed so each layer is sufficiently covered by tire tracks. For dams over 20 feet high, special equipment, such as sheepsfoot rollers, should be used.

Figure 33 The sod and topsoil in a pond construction area can be stockpiled for later use

